ZENITH SPECTRUM COMPATIBLE HDTV SYSTEM

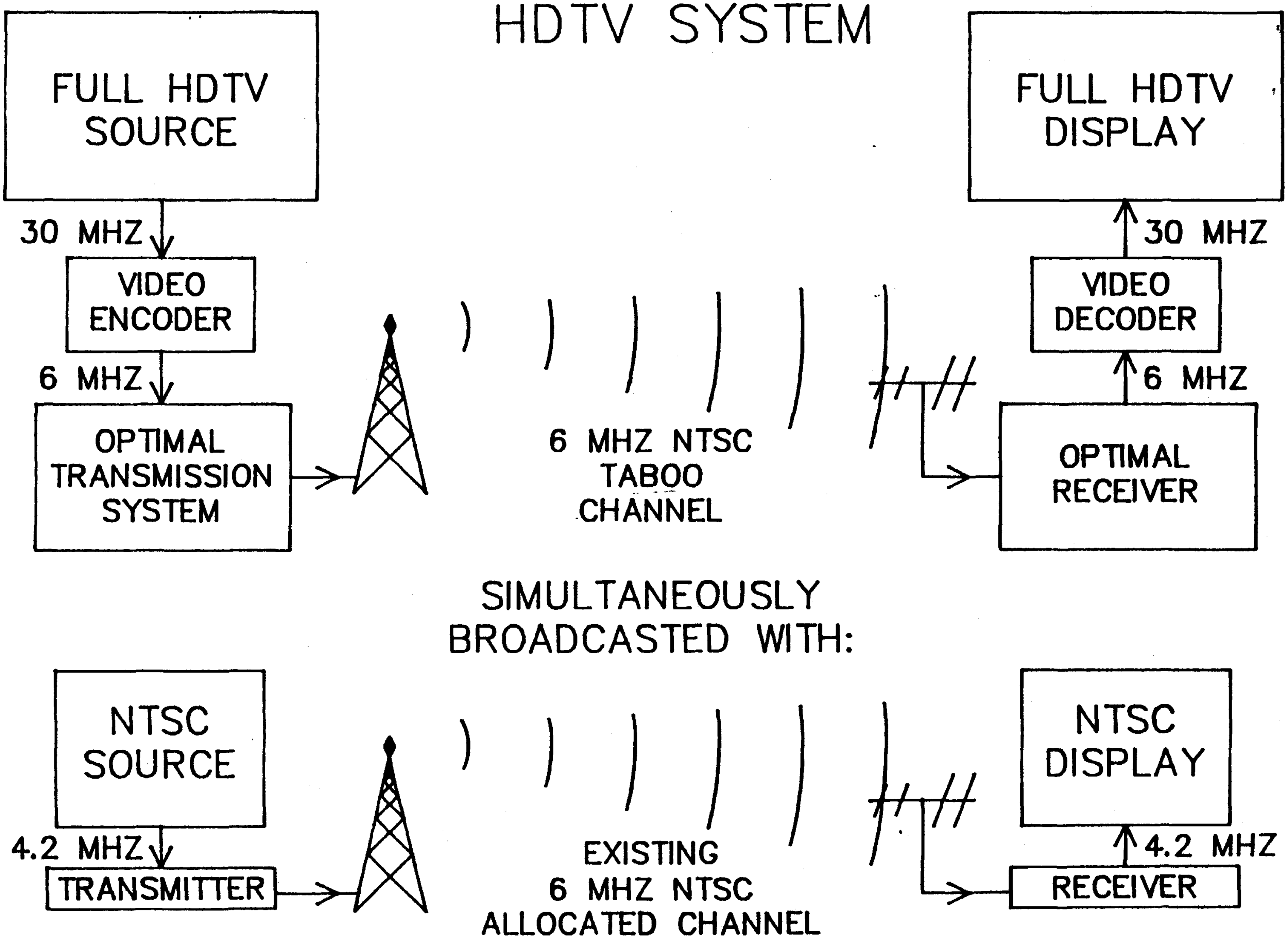


TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

TECHNICAL PROPOSAL

1. GENERAL INTRODUCTION

The Zenith Spectrum Compatible HDTV System is unique in achieving the following major attributes:

- o A video encoding system that allows full high definition transmission, including two digital audio signals, in a 6 MHz channel.

- o A simulcast transmission system that allows nearly Taboo-free use of the VHF/UHF spectrum without causing interference to existing NTSC services.

  - Cochannel operation which enables equal desired NTSC to equivalent undesired HDTV field strength levels.

  - Effective elimination of:

    VHF and UHF Adjacent Channel Taboos
    UHF Intermodulation Taboos
    UHF I.F. Beat Taboos
    UHF Oscillator Taboo
    UHF Image Taboos

  - Nearly 100% accommodation to provide each VHF and UHF terrestrial broadcaster with a 6 MHz channel for HDTV transmission - in addition to the existing NTSC channel.

- A transmission system requiring average transmitter power that is less than 0.2% of that required for NTSC transmission with the same coverage area.

- An HDTV system incorporating various processing steps that provide the improvement in signal-to-noise required to appreciate HDTV pictures.

- An HDTV system also ideally suited for cable transmission without rebuilding cable plants.

- An HDTV video encoding system that lends itself to satellite FM transmission as well as tape recording.

- An HDTV system which may be encrypted to provide security in premium program situations.

- An HDTV system which provides transcodability to NTSC via a simple decoder.

2. OPTIMUM USE OF 6 MHZ CHANNEL IN A TABOO ENVIRONMENT

2.1 REVIEW OF TABOO CONSIDERATIONS

To understand the design evolution of the Zenith HDTV system and how it achieves the above objectives, it is desirable to examine some aspects of the present NTSC system, why the Taboos are there and what can realistically be expected with regard to their elimination or reduction in an NTSC environment.

The Taboos are a set of requirements for minimum distance separation between full power television transmitters for certain VHF and UHF channel combinations. These restrictions were established by the FCC based on NTSC television receiver performance when subjected to signals on Taboo channels. They result in restrictions in the assignments of television broadcast stations and thus prevent efficient spectrum usage.

It has been a long term objective of the FCC to eliminate or reduce the Taboos.

Double conversion approaches, which in principle could eliminate some (the I.F. related) of the Taboos, have been investigated by the TV industry as well as by FCC funded efforts. Configurations of this nature have not been commercialized for broadcast television receivers to the best of our knowledge in any of the world's markets. Some of the reasons are:

- degradation of VHF performance

- concern about achievement and control of UHF noise performance in mass production

- increase in cost and complexity without demonstrable benefit to the consumer

- incompatibility with the commercial requirement to tune CATV channels which now extend continuously into the UHF band

Even if the I.F. related Taboos could be eliminated by double conversion approaches in the receiver, the adjacent channel and non-linear intermodulation Taboos would continue to be dominant. In addition, whatever advantage in spectrum allocation would result could only be realized after the large majority of the existing 160 million NTSC receivers are retired.

An examination of the interference conditions that led to the establishing of the Taboos and the related dominant interference mechanisms in receivers shows that all Taboo interferences for NTSC signals are either linearly or non-linearly proportional to the peak picture and/or sound carrier, and sometimes chroma subcarrier, levels. This observation has led Zenith to design an HDTV transmission system that avoids the high peak power during sync and also avoids subcarriers. In doing so, significant improvement in interference caused to NTSC reception on existing receivers by HDTV systems operating on Taboo channels is achieved.

In addition to tailoring the RF spectrum to eliminate Taboos, by examining the nature of the remaining interference, Zenith has developed additional signal processing steps and techniques which further reduce the absolute interference or its visibility. These same signal processing steps and techniques also help to make the Zenith Spectrum Compatible HDTV signal rugged and robust.

The various individual signal processing steps and techniques will be discussed below from the viewpoint of impact on Taboo channel interferences. A block diagram showing an overview of the transmission system and the order of the processing steps is shown in Fig. 2-1. For more detailed descriptions, the reader is referred to Sections 3 and 4.

2.2 TRANSMISSION PROCESSING

2.2.1 SEPARATION OF VIDEO INTO TWO FREQUENCY BANDS AND LOW FREQUENCY REMOVAL

The spectral density of off-air NTSC video is shown in Fig. 2-2. The spectrum has been averaged over a one-hour period. Except for the chroma at 3.58 MHz and the sound at 4.5 MHz, the spectrum decreases exponentially with most of the energy concentrated within the first-half MHz. This dominant characteristic is true for practically all video signals and indicates that the spectrum is not used in an efficient manner. For optimum transmission and minimum interference, the spectrum should be processed to match the noise characteristics of the channel while minimizing the transmitted power. For white channel noise, the spectrum would have to be flattened.

The approach taken in the Zenith Spectrum Compatible System is to separate the spectrum into two frequency bands (Fig. 2-3). The high-frequency band, which represents most of the spectrum, is analog-processed for transmission. The entire high-frequency band represents a small percentage of the total video signal power. The low-frequency band, the bandwidth of which is under 0.2 MHz, represents most of the video signal power. As will be explained in detail later, the low-frequency band signal is digitized and then

ZENITH TRANSMISSION AND RECEIVER PROCESSOR SYSTEM

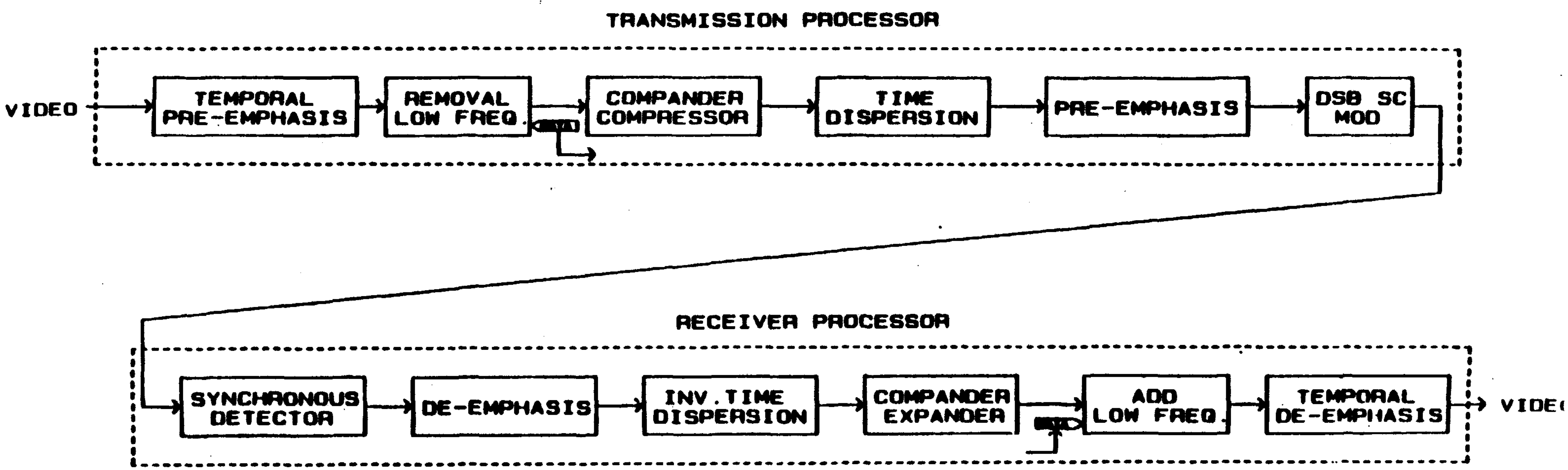


Figure 2-1

ENCDEC1.DRW
ZENITH
9/1/88

Off Air NTSC Video

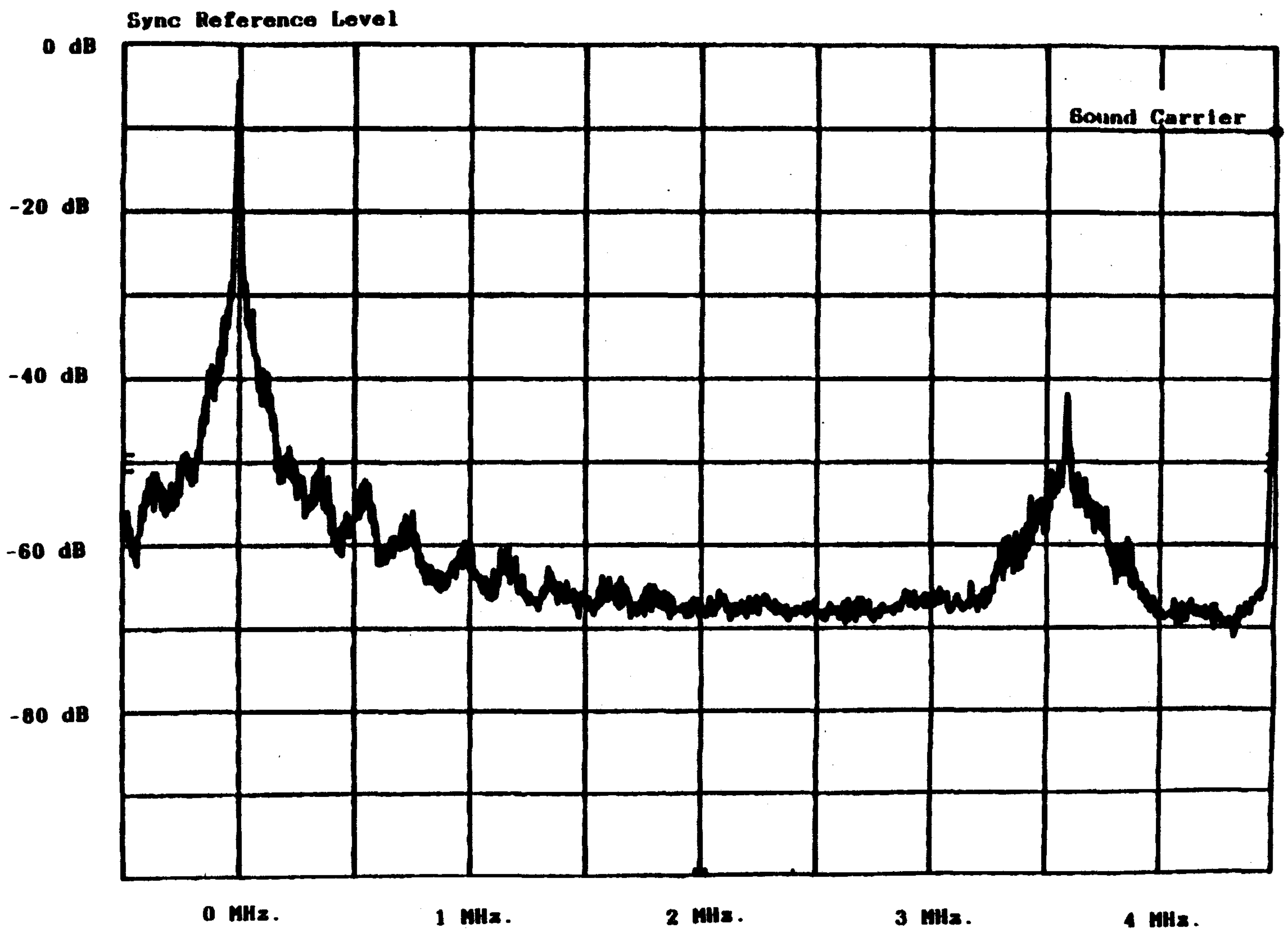
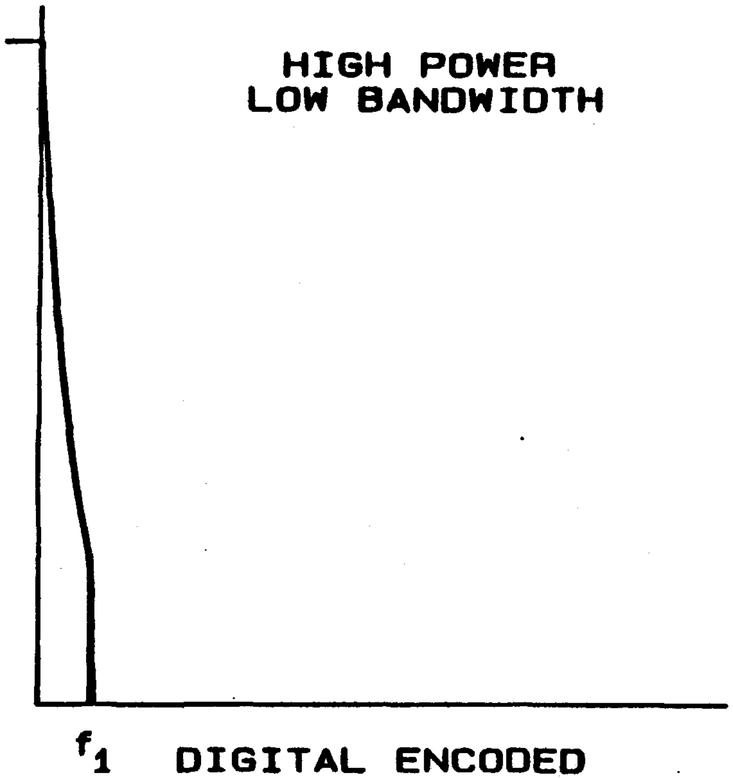


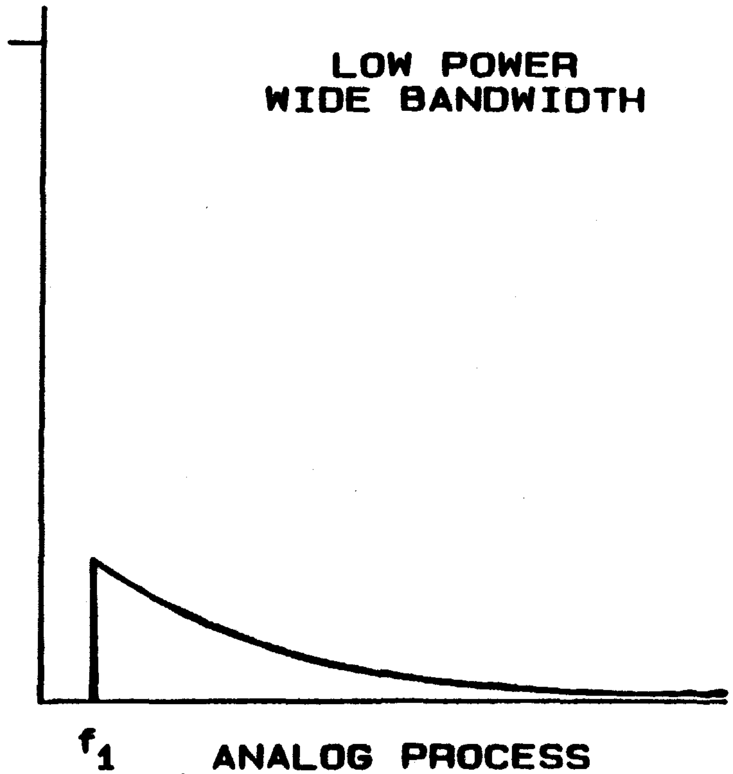
Figure 2-2

Zenith
9/1/88

SEPARATION OF VIDEO INTO TWO FREQUENCY BANDS



DIGITAL ENCODED FOR TRANSMISSION



ANALOG PROCESS TRANSMISSION

Figure 2-3

ZENITH
9/1/88

digitally encoded for transmission. A low bit rate is adequate to represent this signal because of its narrow bandwidth. The digital data, which includes synchronization information, is transmitted during the vertical blanking interval. The spectrum of a processed video signal, with the low-frequency band separated out, is shown in Fig. 2-4. As can be seen, the spectral energy is much lower.

By separating the bands and transmitting the low-frequency band digitally, and the high-frequency band analog, the resultant transmitted signal has a flatter spectrum and reduced power.

2.2.2 HDTV SCANNING PARAMETERS DIRECTLY RELATED TO NTSC SCANNING PARAMETERS

The video encoding employs a scheme whereby the encoded high definition image information is transmitted at the standard NTSC line and field rates of 262.5 lines per field and 59.94 fields per second. This allows the Zenith HDTV system to take full advantage of precision carrier offset (in the vicinity of the 1.75 MHz difference frequency) and to optionally lock vertically to the dominant NTSC channel which is receiving interference from the HDTV signal. Since data in the vertical interval of the HDTV signal will be the most visible interference, vertical locking hides that interference in the vertical interval of the NTSC channel.

In addition, the use of suppressed carrier modulation of two quadrature carriers in the center of the channel results in cochannel interference appearing as a 1.75 MHz component which not only exhibits reduced visibility but also is free of the low-frequency sync timing interference that frequently becomes dominant in typical NTSC receivers.

Video with Low Frequencies Removed

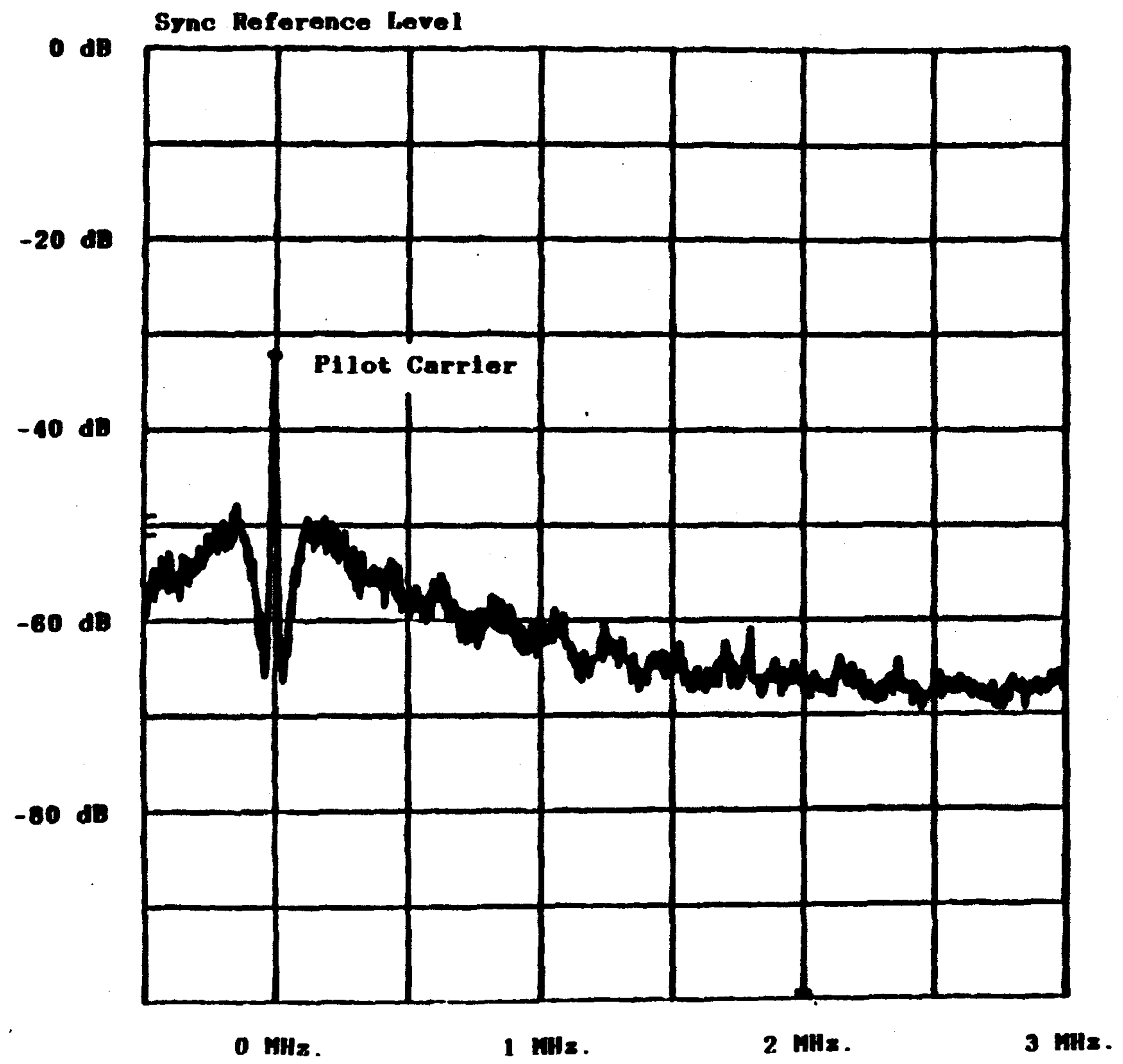


Figure 2–4

Zenith
9/1/88

2.2.3 TEMPORAL FILTERING (FIELD PROCESSING)

A temporal pre-emphasis filter is used in the transmitted signal to reduce transmission of redundant (static) picture information and, therefore, reduces cochannel interference from HDTV into NTSC. This process is similar to field combing.

At the HDTV receiver, a complementary temporal de-emphasis is used which not only cancels the temporal pre-emphasis at the transmitter but also reduces interference and noise. In addition, when precise offset to an NTSC cochannel is used, the receiver temporal de-emphasis will also substantially reduce cochannel interference from NTSC into HDTV.

2.2.4 COMPANDING OF HIGH FREQUENCY VIDEO

Although average power of the video signal is significantly reduced by both low-frequency removal and temporal pre-emphasis, peak power during active video is not reduced. To minimize interference caused by the HDTV signal, it is important that this peak power is also reduced. Since the temporal pre-emphasis boosts the peak signal on moving video relative to stationary video, the highest peak energy will actually result from moving edges in the image. To control this peak signal power caused by moving edges, a non-linear time-domain process, called companding, is used.

As implemented, a compressor at the encoder, raises the level of small amplitude signals and lowers the level of high amplitude signals, thereby limiting peak signals. At the receiver, the decoder is equipped with an expander which is complementary to the encoder compressor.

Since the compressor lowers the level of high amplitude signals sent out of the encoder, visible interference caused by the peaks of the HDTV signal into other services is reduced. In many instances, since interference mechanisms are non-linear, the reduction in visibility decreases exponentially with the peak power reduction.

In addition to reducing interference, the compressor also helps to improve the signal-to-noise ratio of the low amplitude HDTV signals, by raising the level of these signals before being sent.

The effect companding has on noise will be to make the decoder output signal-to-noise ratio dependent on the level of the input signal, thus making the noise multiplicative. The companded signal subjectively has a considerably improved signal-to-noise ratio.

2.2.5 TIME DISPERSION

Because of the low frequency removal, peaks in the transmitted analog signal only occur as pulses. A linear filter, which disperses the energy of these pulses over time while at the same time reducing their amplitude, is used to further reduce peak power. The reduction in peak power produces a corresponding reduction in the interference which the HDTV signal can cause. As mentioned before, the improvement changes exponentially with reduction in peak power.

25

A complementary dispersive filter in the receiver not only restores the HDTV signal to its original shape and amplitude, but it also reduces the visibility of interference received by the HDTV receiver. Any interference is time dispersed and reduced in amplitude.

2.2.6 HIGH FREQUENCY PRE- AND DE-EMPHASIS

Pre-emphasis of the analog signal before transmission is included for two reasons. First, to improve the signal-to-noise ratio of the HDTV signal, and second to make the receiver IF filter practical. Pre-emphasis raises the level of high-frequency components which are transmitted.

De-emphasis in the receiver lowers the level of the received high-frequency components and complements the transmitter pre-emphasis. The receiver de-emphasis also lowers the amplitude of high-frequency interference, which includes the offset carrier energy of NTSC cochannel at 1.75 MHz.

The de-emphasis in the receiver is included as part of the IF filter. This makes the receiver filter economical and practical.

2.3 MEASURED PERFORMANCE

Laboratory tests of R.F. of parts of the system, believed to be conservatively representative of the interference performance of the complete HDTV system, have demonstrated the following results in tests conducted to evaluate interference by HDTV into NTSC.[1]

Also included for comparison are U/D ratios for thresholds of perceptible interference from NTSC into NTSC for the particular Taboos. These data are derived from the 1987 FCC Report FCC/OET TM-1 by Hector Davis.

2.3.1 COCHANNEL INTERFERENCE

The threshold of perceptible interference at the NTSC receiver occurred at undesired HDTV to desired NTSC signal levels at the input of the receiver of -6 dB.[2]

For 6 dB front-to-back ratio of the receiving antenna this corresponds to 0 dB field strength ratio, which in turn requires a minimum cochannel separation of 127 kM at VHF and 109 kM at UHF.[3] Without adjacent channel restrictions, 160 kM separation results in 99.7% of all present broadcast licensees being accommodated with an additional available 6 MHz channel.

1/ Undesired to Desired (U/D) signal ratios for HDTV are based on calibration of the HDTV signal in reference to the NTSC signal for equivalent signal-to-noise ratios.
2/ See PS/WP3-0051, "Spectrum Allocation Studies, Station Separations and Desired to Undesired Ratios."
3/ See Table 6 PS/WP3-57, "Preliminary Analysis of VHF and UHF Spectrum Scenarios."

For comparison CCIR, Report 306-4, recommends 22 dB cochannel protection for NTSC into NTSC with precision offset.

Temporal filtering, which was not part of the laboratory tests, can be expected to provide a further reduction in cochannel interference visibility of 6 to 10 dB.

2.3.2 ADJACENT CHANNEL (n ± 1)

The absence of a sound subcarrier has eliminated the primary interference mechanisms to both the lower (n - 1) and the upper (n + 1) adjacent channels.

The elimination of sync and low-frequency video from the modulating signal and the suppression of the carrier have reduced the peak envelope of the R.F. signal such that cross modulation, which is the secondary interference mechanism for n ± 1, and which is proportional to the square of the undesired R.F. envelope, is vastly reduced.

The threshold of perceptible interference is at U/D ratios considerably greater than 30 dB.

As reference for NTSC into NTSC, the corresponding value ranges from 2 to 20 dB.

2.3.3 INTERMODULATION (n ± 2, n ± 3, n - 4)

The so-called Intermodulation Taboos in NTSC are all caused by cross modulation. Thus, for the same reasons cited above, they are essentially eliminated as Taboos when utilizing the Zenith Spectrum Compatible System. The threshold of perceptible interference is at U/D ratios well above 40 dB.

As reference for NTSC into NTSC, the corresponding value ranges from 13 to 40 dB.

2.3.4 HALF I.F. (n + 4)

This Taboo, although listed by the FCC under Intermodulation Taboos, is caused by a different mechanism (the difference frequency between the second harmonic of the interfering frequency and the second harmonic of the local oscillator falls in the I.F. band) which makes it usually dominant over the n ± 2, n ± 3 and n - 4 Taboos.

For the Zenith HDTV system only the lower part of the lower sideband could in principle cause visible interference. The threshold for perceptible interference is at U/D ratios greater than 30 dB.

As reference for NTSC into NTSC, the corresponding value ranges from 4 to 19 dB.

2.3.5 I.F. BEATS (n ± 7, n ± 8)

The n ± 7 Taboo involves a second order beat between the picture carriers of the desired and that of either the n + 7 (or n - 7) channels and results in an I.F. component. The n ± 8 Taboo involves a second order beat between picture and sound carriers of two NTSC signals eight channels apart, resulting in an I.F. component.

As the Zenith HDTV signal has no sync, is suppressed carrier, offset by 1.75 MHz and contains no sound carrier, these Taboos are essentially eliminated (U/D ratios greater than 45 dB).

As reference for NTSC into NTSC, the corresponding value ranges from 0 to 40 dB.

2.3.6 SOUND IMAGE (n + 14)

Only the upper sideband of the HDTV signal could cause visible high frequency interference. Reduced peak RF envelope and suppressed carrier have essentially eliminated this Taboo (U/D ratios greater than 45 dB).

As reference for NTSC into NTSC, the corresponding value ranges from 3 to 28 dB.

2.3.7 PICTURE IMAGE (n + 15)

Only the lower sideband could cause visible interference, but again, because of reduced RF envelope and suppressed carrier transmission, this Taboo has also essentially been eliminated.

As reference for NTSC into NTSC, the corresponding value ranges from -17 to 6 dB.

3. OPTIMUM ENCODING AND DECODING OF VIDEO

3.1 INTRODUCTION

In order to take full advantage of the 6 MHz RF channel, a video encoding and decoding system is used which not only compresses the HDTV signal into 6 MHz, but also converts it into a format which can take advantage of the techniques described above that minimize interference.

Fig. 3-1 illustrates how the video encoding and decoding fit into the overall scheme. The encoding starts with a 787.5 line 59.94 Hz progressively scanned source which is encoded, transmitted, received, decoded, and finally displayed on a 787.5 line 59.94 Hz progressively scanned monitor.

The final display shows a picture with 720 active lines vertically and 1020 lines per width (lpw). The aspect ratio of the source and display is 5:3[4] and the improvement in horizontal resolution over NTSC can be calculated as:

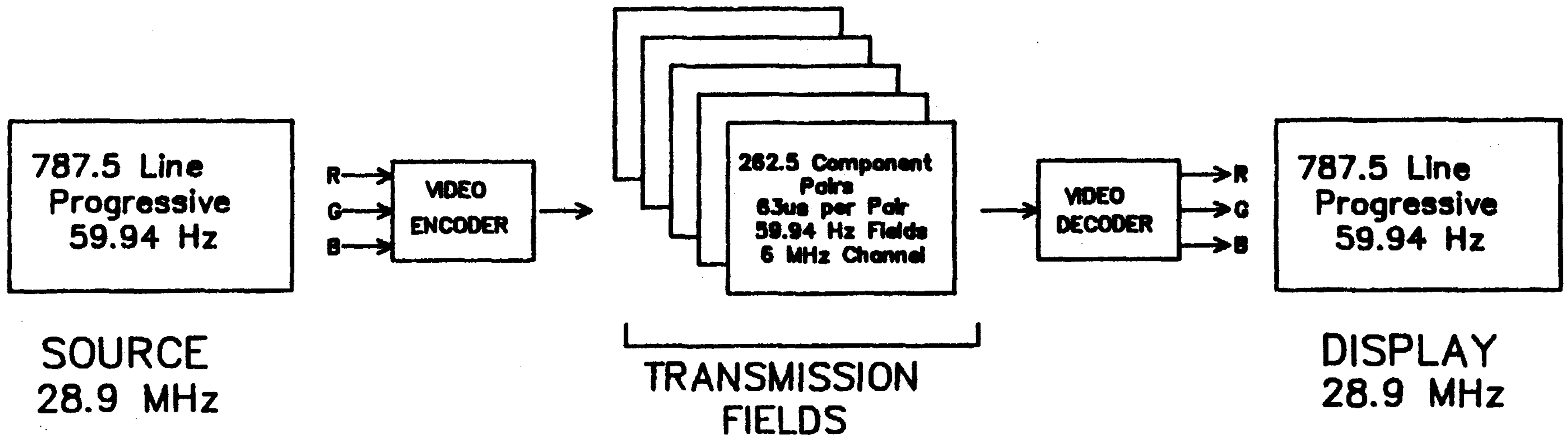
(1020 x 4/5)/(2 x 52.66 uS x 4.2 MHz) = 1.8

4/ The system may also be designed for an aspect ratio other than 5:3. The consequence of a different aspect ratio is a corresponding change in the improvement of horizontal resolution over NTSC. For instance, a 16:9 aspect ratio will result in an improvement in horizontal resolution over NTSC of:

(1020 x 4/5.3333)/(2 x 52.66 uS x 4.2 MHz) = 1.7

A 4:3 aspect ratio will result in an improvement over NTSC of:

(1020 x 4/4)/(2 x 52.66 uS x 4.2 MHz) = 2.3



HD Encoding for Transmission

Figure 3–1

Zenith
9/1/88
fig_3–1